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Canada Centre for Mineral and Energy Technology

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CANMET STRAIN MONITORS FOR HARD ROCK: DESCRIPTION, INSTALLATION, ANALYSIS

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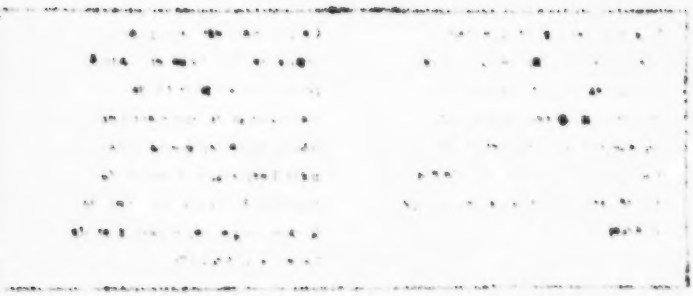
MICROMEDIA

23 pp



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CANMET STRAIN MONITORS FOR HARD ROCK: DESCRIPTION, INSTALLATION, ANALYSIS

by

G. HERGET*

SUMMARY

The CANMET strain monitor has been developed to measure with high resolution (0.0004 mm) the deformation of bore holes in hard rock with diameters of 76 mm, 118 mm and 153 mm. The sensor is similar to a proving ring which is set with wedges into a bore hole. A vibrating wire is used to determine ring deformation. The resonant frequency is determined with continuous or plucking type exciter units. If the bore hole does not close too severely, the rings are easily removed to be used at another location. The easy removal of sensors is also useful for checking ring seating and calibration.

Calibration is stable and linear. If required, sensors can be repaired easily. The design is rugged enough so that mine production blasting at 2m distance will not destroy or dislodge the sensors.

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Key Words: Stress, monitoring, borehole instrumentation

EXTENSOMETRES DE ROCHE DURE DE CANMET: DESCRIPTION, INSTALLATION, ANALYSE

par

G. HERGET*

SOMMAIRE

L'extensomètre de CANMET a été mis au point pour mesurer avec une grande résolution (0,0004 mm) la déformation des trous de sondes de 76, 118 et 153 mm de diamètre dans la roche dure. Le capteur est semblable à un anneau dynamométrique qui est calé dans un trous de sonde. Un fil vibrant mesure la déformation de l'anneau. La fréquence de résonance est déterminée à l'aide de dispositifs d'excitation continue et pulsée. Si le trou de sonde ne se referme pas trop, il est facile de retirer les anneaux pour les utiliser ailleurs ou vérifier s'ils sont bien calés ou étalonnés.

L'étalonnage est stable et linéaire. Au besoin, il est facile de réparer les capteurs. Leur construction est assez robuste de sorte qu'un tir de production ne réussira pas à les endommager ou à les déloger.

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Mots clés: contrainte, contrôle, instrumentation des trous de sonde

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OVERVIEW

Applications

The CANMET strain monitor has been developed to measure the deformation of boreholes in hard rock. The resolution is better than 0.0004 mm and elastic deformation in hard rock can be reliably measured to check finite element predictions, planning assumptions and rock mass stability (Fig 1).

The sensors are available for 76 mm (2.98 in.), 118 mm (4.66 in.), and 153 mm (6 in.) diameter boreholes. Output may be recorded by a pocket size frequency meter or a borehole data logger. The sensors have a stiffness of about 140 MN/m (800 000 lbs/in.).

Description

The CANMET strain monitor consists of a steel proving ring across which a vibrating wire is strung. A built-in exiter unit is used to vibrate the wire at its resonant frequency. The wires resonant frequency which changes with ring deformation is virtually unaffected by temperature and humidity changes. Two diametrically opposed slots cut parallel to the ring's axis in the outer surface with a 3° taper house wedges driven into place with a hydraulic installing tool. The wedges provide a pre-stress to the single axis sensor so that it will stay in contact with the borehole wall during extension or compression of the borehole wall. Pre-stress is in the vicinity of 14 MPa (2000 psi).

Features

- High precision, high resolution sensing system with rugged design
- Acceleration proof
- Units can be removed at the end of an investigation or for recalibration

- Sensor monitors one diameter only but installation of 4 sensors in one borehole is common
- Split tube mechanical seats are used to clamp vibrating wires into place which allows easy wire replacement
- Stable calibration because of precision wedge system
- Vibrating wire mounted at right angles to loading direction
- Hand held read out or automatic data collection
- Range of 0.2 mm (0.008 in.) with a resolution of 0.0004 mm (0.000016 in.)

Accessories

- Read out unit
- Data logger (Fig. 2)
- Installing tool (Fig. 3)
- Installing rods
- SR-11 smart logger for rings equipped with plucking system (Fig. 4)

How to Order

1. Size of borehole
2. Cable length
3. Thermistor
4. Type of read out
5. Installing tool

INSTALLATION

Assembly

The CANMET strain monitor is available for 76 mm (2.98 in.), 118 mm (4.66 in.), and 153 mm (6 in.) diameter boreholes. The wedge system allows the following range of borehole diameters to be used: (73-80 mm), (116-126 mm), and (149-159 mm). The sensors are preferably installed in diamond drilled holes but percussion drilled holes reamed to the required diameter are also suitable.

The CANMET strain monitor is shipped from the supplier complete with wedges and calibration chart. The wedges are wired together and are mounted on the rings as shown in Figure 1.

The strain monitor ring is attached to the arms of the installation tool with brass screws as shown in Figure 3. For installation the deep end of the 3 degree slot on the ring must face the collar and the wedges must be in line with the slot in the push bar of the installation tool. The centre of the brass holding screws may be drilled out to achieve a lower seating pressure.

Orientation

The wedge location on the borehole wall determines the diameter along which the borehole deformation is monitored. The orientation switch on the installation tool is mounted to allow the selection of locations around the borehole wall in 45° increments. An installation of four rings (at 0° (horizontal), 45°, 90° (vertical) and 135° with the angle measured anticlockwise from horizontal right for an observer looking into the drill hole) provides one redundant reading. This allows calculation of measurement errors and assessment as to the rocks elastic behaviour.

To set the mercury switch for vertical orientation (90°) the mercury switch is moved to the 90° position and screwed in place. It is advisable to push the installation tool into the borehole with the orientation light on and on arrival at the desired location rotate the installation tool clockwise by 10 degrees until the light just flickers.

With the mercury switch set to the required vertical orientation, the hydraulic hoses are connected to the hydraulic pump. Quick connect couplings are available to hook up the oil line to the cylinder of the installation tool. The cable to the CANMET strain monitor needs to be brought out of the hole and rods of sufficient length connected to the installation tool to reach the desired location in the borehole. The assembled unit is pushed to the desired location in the borehole and rotated so that the wedges are in the required position. Following this, the hydraulic pump is activated. When an adequate pre-load is achieved, the brass screws will shear and the installation tool can be withdrawn from the borehole. During installation the sensor is connected to a read out unit and the frequency change during installation is noted, e.g. 200 Hz. The frequency range is commonly 600-1800 Hertz. If the vibrating wire units are installed in locations with large temperature variations, e.g. more than $\pm$ 8°C, temperature measurements are recommended with a thermistor.

Removal

For the removal, a heavy screw is mounted on the push bar of the installing tool. This is pushed into the hole and on contact with the ring to be removed, the tool is rotated until the retraction arms pass the ring. Then the installing tool is rotated for the keys of the arms to engage the wedges. Engagement is complete if the tool cannot be pulled back. The hydraulic pump is then activated. As the push bar pushes against the front plate of the sensor, the retraction arms hold the wedges in place and the ring is forced off the wedges. When the wedges are loose, the sensor is retracted. If the wedges separate from the sensor, the sensor can be pulled out with the readout wire and the wedges recovered separately with a hook or a magnet.

CALCULATIONS OF STRESSES AND STRAINS FROM BOREHOLE DIAMETER CHANGES

Stresses acting in a rock mass or a concrete structure possess magnitude and direction. Stress magnitudes are described by shear and normal stress components. Only for principal stress directions do shear components vanish and magnitude is described entirely by normal components.

Three principal stress magnitudes and their directions define a three dimensional stress field. Drilling a borehole into rock or concrete creates a void and the stresses are bridged through the borehole wall. Stress magnitudes and directions are therefore distorted in the vicinity of a borehole, but can be readily calculated for isotropic homogeneous elastic materials.

Ideally the three-dimensional stress tensor should be determined at each monitoring location. However, for an instrument monitoring borehole diameter changes it would require a minimum of three boreholes, preferably drilled at right angles to each other with a minimum of two sensors each monitoring diameters in mutually independent directions. This effort is often not warranted because before monitoring locations are instrumented, either computer analysis or experience will have identified the critical directions for which monitoring is significant.

The analysis below restricts itself to two dimensional stress/strain analysis for the calculation of principal strains and stresses.

Definitions:

$$\text{Stress} = \frac{\text{Load}}{\text{Area}} \quad (\text{lbs/in}^2,\ \text{N/m}^2,\ \text{MPa})$$

$$\text{Strain} = \frac{\text{Change of diameter}}{\text{Original diameter}} = \frac{U}{d} \quad (\text{in./in};\ \text{mm/mm},\ \text{dimensionless})$$

Elastic Modulus = $\frac{\text{stress}}{\text{strain}}$ (lbs/in^2, N/M^2, MPa) - Hooke's Law

The CANMET strain monitor (MSMS) indicates changes of borehole diameter by changes of vibrating wire frequency. Before shipment to the customer, each instrument is calibrated for frequency changes with deformation and the calibration factor is calculated. For a typical instrument the calibration factor is 0.0004 mm/Hz.

Borehole diameter deformation = change in Hz x calibration factor, e.g. U = 59Hz x 0.0004 mm/Hz = 0.0236 mm

For a measurement in a 76 mm diameter borehole the diametral strain is :

$$\Delta d = \frac{U}{d} = \frac{0.0236 \text{ mm}}{76\text{mm}} = 0.000310 \text{ mm/mm} = 0.000310\varepsilon$$

The deformation U of a borehole diameter is given according to elastic theory by

$$U = \frac{d}{E}[(6_1+6_2)+2(6_1-6_2)\cos 2\theta]$$

with:

U = deformation of borehole diameter

d = borehole diameter

E = elastic modulus

6_1 = maximum principal stress

6_2 = minimum principal stress

θ = angle from horizontal counter clockwise

Three measurements of strain along a diameter are necessary to calculate the strain ellipse and to identify in the plane of measurement the magnitude of the principal strains and their directions. With the knowledge of the elastic modulus and the Poisson's ratio of the rock material, principal stresses and their directions may be calculated for a homogenous,

isotropic, elastic material. For each direction of measurement an equation like the above is required. These are then combined and solved for the principal strains.

If a rectangular pattern of sensor orientation is maintained for the CANMET strain monitors, the solution below will provide the magnitude and orientation of principal stresses.

Rectangular Pattern:

Instrument 1 is orientated with $\theta = 0°$ from horizontal with the observer looking into the borehole

Instrument 2 is oriented with $\theta = 45°$ anticlockwise from horizontal

Instrument 3 is oriented with $\theta = 90°$ anticlockwise form horizontal

As an example, the following strains were obtained after monitoring by applying the calibration factor and dividing by the borehole diameter:

1. $\theta = 0°$ (horizontal) = $\varepsilon_0 = 0.000310$
2. $\theta = 45°$ (45 degree) = $\varepsilon_{45} = 0.000080$
3. $\theta = 90°$ (vertical) = $\varepsilon_{90} = 0.000050$

Maximum principal strain (ε_1):

$$\varepsilon_1 = 0.5\ (\varepsilon_0+\varepsilon_{90}) +0.5[2(\varepsilon_0-\varepsilon_{45})^2 + (\varepsilon_{45}-\varepsilon_{90})^2]^{0.5}$$

$$\varepsilon_1 = 0.5\ (310+50) + 0.5\ [2(310-80)^2 + (80-50)^2]^{0.5} = \underline{0.000343\varepsilon}$$

Minor principal strain (ε_2):

$$\varepsilon_2 = 0.5(\varepsilon_0+\varepsilon_{90}) - 0.5[2(\varepsilon_0-\varepsilon_{45})^2+(\varepsilon_{45}-\varepsilon_{90})^2]^{0.5}$$

$$\varepsilon_2 = \underline{0.000017\varepsilon}$$

The principal strain directions are:

$$\tan 2\theta(\varepsilon_1,\varepsilon_2) = \frac{\varepsilon_{45}-(\varepsilon_0+\varepsilon_{90})}{\varepsilon 0 - \varepsilon 90} = \frac{160-360}{260} = -0.769$$

$$\arctan(-0.769) = -37.56 = 2\theta$$

$\theta = -18.78°$ below horizontal identifies the direction of one of the principal strains ε_1 or ε_2. $\theta_{\varepsilon 1}$, must make an angle of less than 45° with the algebraically greater normal strain, which in this case is 0.000310ε. Thus the -18.78° identifies the direction of the maximum principal compressive strain.

For the elastic isotropic case the directions of principal stresses agree with those of the principal strains.

With magnitude known for the principal strains (ε_1 = maximum, ε_2 = minimum) principal stress magnitudes are obtained as follows:

Maximum principal stress (σ_1):

$$\sigma_1 = \frac{E(\varepsilon_1+R\,\varepsilon_2)}{1-R^2}$$

For the above case with elastic modulus (E) = 69 GPa and Poisson's Ratio (R) = 0.25:

$$\sigma_1 = \frac{69\text{GPa}\ (0.000343 + 0.25 \times 0.000017)}{1 - 0.25^2} = 25.6\ \text{MPa}$$

Minor principal stress (σ_2):

$$\sigma_2 = \frac{E(\varepsilon_2 + R\,\varepsilon_1)}{1-R^2}$$

$$\sigma_2 = \frac{69\text{GPa}\ (0.000017 + 0.25 \times 0.000343)}{1-0.25^2} = 7.6\ \text{MPa}$$

Assessment of Read Out Precision

As mentioned earlier, three readings along three diameters are required to determine the strain ellipse and obtain the principal stresses and their magnitude in the plane of the borehole.

If one additional diameter is monitored, e.g. at 135°, it is possible to calculate the strain ellipse 4 times by combining every time a different set of three diameters, e.g.: (123, 124, 234, 341). If the solutions for the four sets agree, then the conditions of elasticity are fulfilled and the monitoring procedure is very precise. If not, then the redundant reading allows calculation of a solution of best fit and a calculation of error according to the method of least squares.

Effect of Stress Parallel to the Borehole

As quoted in Herget, 1988, p.72 the relationship for principal stresses and strains in three dimensions is as follows:

I. $\varepsilon x = [\sigma x - R(\sigma y + \sigma z)]/E$

II. $\varepsilon y = [\sigma y - R(\sigma x + \sigma z)]/E$

III. $\varepsilon z = [\sigma z - R(\sigma x + \sigma y)]/E$

The solution for σx, σy, σz is as follows:

$$\text{I.} \quad \sigma x = E.\ \varepsilon x + R(\sigma y + \sigma z)$$

$$\text{II.} \quad \sigma y = E.\ \varepsilon y + R(\sigma x + \sigma z)$$

$$\sigma x = \frac{E\ (\varepsilon x - \varepsilon y)}{(1 + R)} + \sigma y$$

$$\text{III.} \quad \sigma z = E.\ \varepsilon z + R(\sigma x + \sigma y)$$

$$\sigma z = E.\ \varepsilon z + R\left[\left(E(\varepsilon x - \varepsilon y)/(1 + R)\right) + \sigma y\right) + \sigma y\right]$$

$$\sigma z = E.\ \varepsilon z + E.R\ \frac{(\varepsilon x - \varepsilon y)}{1+R} + 2R\sigma y$$

$$\text{II.} \quad \sigma x = E.\ \varepsilon y + R(\sigma x + \sigma z)$$

$$\text{III.} \quad \sigma z = E.\ \varepsilon z + R(\sigma x + \sigma y)$$

$$\sigma z = \sigma y - \frac{E(\varepsilon y - \varepsilon z)}{1 + R}$$

$$E.\ \varepsilon z + \frac{ER(\varepsilon x - \varepsilon y)}{1 + R} + 2R\sigma y = \sigma y - \frac{E(\varepsilon y - \varepsilon z)}{1 + R}$$

$$\sigma y = \frac{E(\varepsilon y - R(\varepsilon z + \varepsilon x - \varepsilon y))}{(1-2R)(1 + R)}$$

REFERENCES

Herget, G. "Stresses in rock", A.A. Balkema, Rotterdam, 1988, 179 pp.

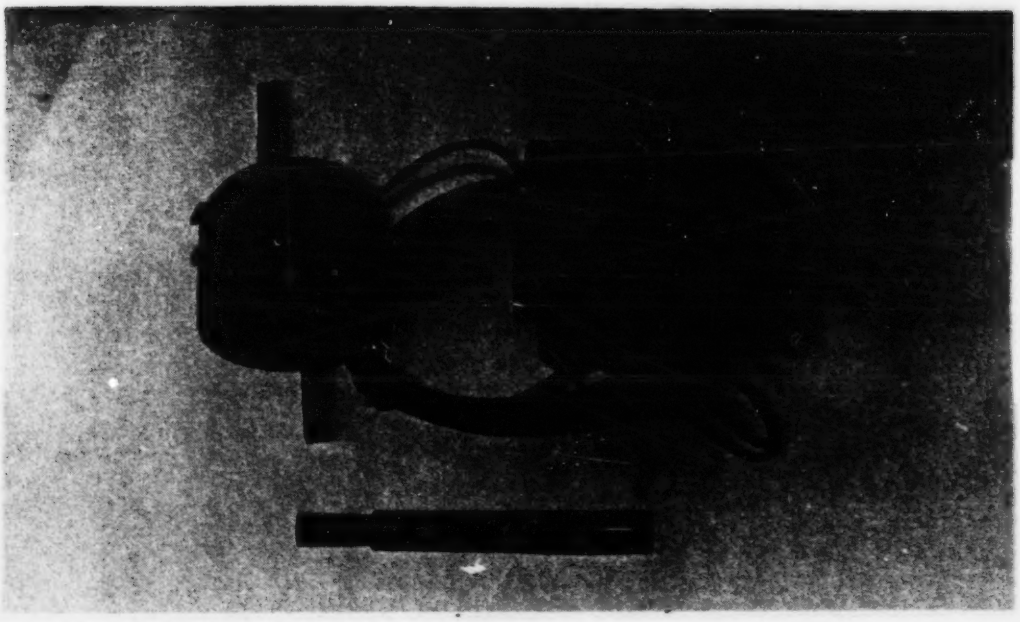

Fig. 1. CANMET strain monitor and hand held readout unit

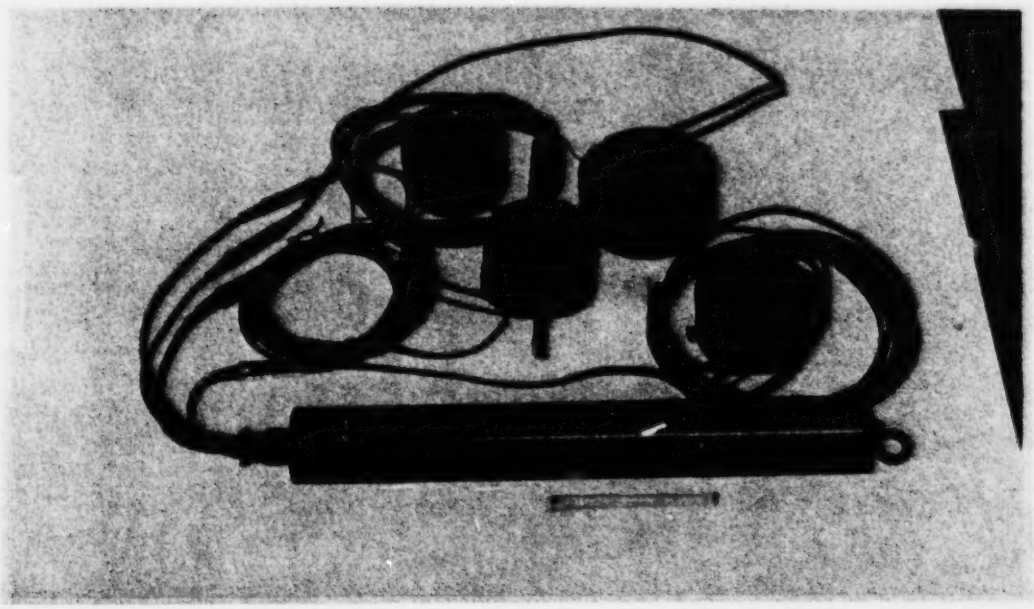

Fig. 2. RBR data logger and four CANMET strain monitors

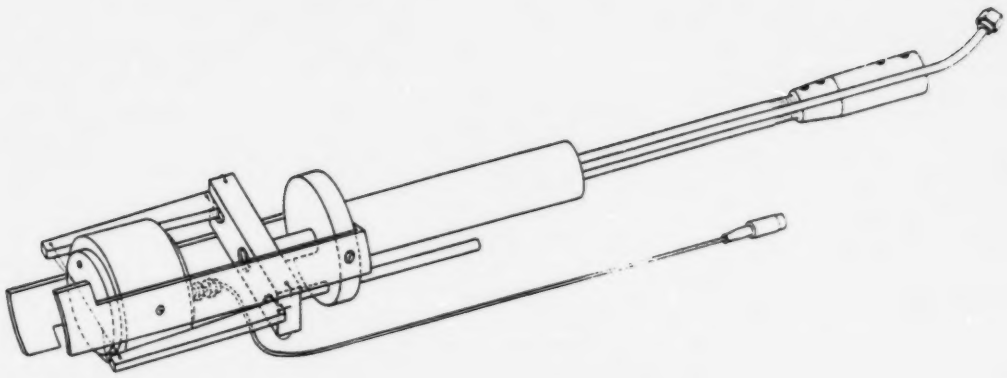

Fig. 3. Installing tool

Fig. 4. SR-11 smart logger for strain monitors with plucking exciters

APPENDIX I

Computer Programs

Two short computer programs are provided to estimate stress changes from borehole deformation measurements in elastic rock.

All stress monitoring programs should aim to calculate the three-dimensional stress field with error calculations for all components. This requires measurements of strain in more than six independent directions (3 boreholes). In many cases such an instrumentation set up is not available and the need arises to analyse borehole deformation data of a more limited scope. This is, however, sufficient to identify semi-quantitatively the effect of excavation activity on another part of the excavation. For this purpose the following programs are provided:

HV Calculates stresses from monitoring a horizontal and a vertical diameter which are assumed to be principal directions

HV45 Calculates stresses from the monitoring of three diameters arranged in a 45 degree pattern starting from horizontal anticlockwise

All programs contain an option to take into account the effect of the stress parallel to the drillhole. Throughout the program the following symbols are used:

Appendix I continued

E = Elastic modulus in GPa

R = Poisson's ratio

B = Borehole diameter in mm

N = Test number (881102 = 1988, November, day 2)

H0, H4, H9 = Readings of frequency in Hertz for the horizontal, 45°, and vertical directions

K0, K4, K9 = Calibration factors in mm/Hz for horizontal, 45°, and vertical directions

$\varepsilon 1$, $\varepsilon 2$ = Major and minor principal strains in plane perpendicular to borehole axis

θ = Angle anticlockwise from horizontal

S1, S2 = Major and minor principal stresses in plane perpendicular to borehole axis

A = Strain obtained parallel to borehole axis with extensometer, etc.

A1 = Stress parallel to borehole axis

Example:

Example of borehole diameter changes N = 881102, B1 = borehole diameter of 76 mm.

Readings in Hz:	Calibration factor:	Borehole strains:
H0 = 59	K0 = 0.00040	$\varepsilon 0$ = 0.000310
H4 = 16	K4 = 0.00038	$\varepsilon 4$ = 0.000080
H9 = 9	K9 = 0.00042	$\varepsilon 9$ = 0.000050

Elastic modulus = 69GPa

Poisson's ratio = 0.25

```
100 REM PROGRAM HV45-MRL/CANMET-HERGET NOV. 1989
110 REM PROGRAM CALCULATES STRESS CHANGES IN MPA FOR CHANGES IN FREQUENCY
120 REM (HERTZ) RECORDED BY CANMET STRAIN MONITORS IN BOREHOLES.
130 REM COMPRESSIVE STRESSES ARE POSITIVE AND REDUCTION IN LENGTH PRODUCES
140 REM POSITIVE STRAINS.
150 REM INPUT IS: 270 E=ELASTIC MODULUS(GPA),280 R=POISSON'S RATIO,
160 REM 290 B1=BOREHOLE DIAMETER(MM), 310 KO=CALIBRATION FACTOR(MM/HZ) FOR
170 REM FREQUENCY READING(HZ) IN HO(=HORIZONTAL) DIRECTION, 320 K4=
180 REM CALIBRATION FACTOR (MM/HZ) FOR FREQUENCY READING(HZ) IN H4(=45 DEGREE)
190 REM DIRECTION, K9=CALIBRATION FACTOR FOR H9(=VERTICAL) DIRECTION. 400
200 REM DATA 881121(DATE OF MEASUREMENT,N),59(HO READING),116(H4 READING),9(H9
210 REM READING),100(A=STRAIN READING FOR DIRECTION PARALLEL TO BOREHOLE
220 REM FROM EXTENSOMETER,ETC.. IF READING FOR "A" IS NOT AVAILABLE, INPUT "0"
230 REM AND S1 AND S2 ARE SECONDARY PRINCIPAL STRESSES CORRESPONDING TO
240 REM STRAINS E1 AND E2. IF READINGS FOR "A" ARE AVAILABLE, THE PROGRAM
250 REM ASSUMES THAT THE BOREHOLE DIRECTION IS A PRINCIPAL STRESS DIRECTION
260 REM AND CALCULATES THREE PRINCIPAL STRESSES.
270 REM THE ANGLE FOR THE MAJOR OR MINOR STRESS PERPENDICULAR TO THE
280 REM BOREHOLE AXIS IS GIVEN IN DEGREES ANTICLOCKWISE (+) FROM HORIZONTAL
290 REM RIGHT WITH AN OBSERVER LOOKING INTO THE DRILLHOLE.
300 E=69
310 R=.25
320 B1=76
330 KO=.0004
340 K4=.00038
350 K9=.00042
360 LPRINT"ELASTIC MODULUS(GPA), POISSON'S RATIO, BOREHOLE DIA.(MM)"
370 LPRINT E,R,B1
380 LPRINT"CALIBRATION FACTORS KO,K4 AND K9 IN MM/HZ"
390 LPRINT KO,K4,K9
400 READ N,HO,H4,H9,A
410 DATA 881121,59,16,9,100
600 EO=1000000!*HO*KO/B1
610 E4=1000000!*H4*K4/B1
620 E9=1000000!*H9*K9/B1
630 LPRINT"DATE, BOREHOLE MICRO-STRAINS AT 0, 45, AND 90 DEGREES"
640 LPRINT N, EO, E4, E9
650 L1=(EO+E9)/2
660 L2=.70711*((EO-E4)^2+(E4-E9)^2)^.5
670 E1=(L1+L2)
680 E2=(L1-L2)
690 LPRINT"AXIAL   AND    MAJOR AND MINOR MICRO-STRAINS"
700 LPRINT A, E1, E2
710 S1=(.001*E*(E1+R*E2)/(1-R^2))
720 S2=(.001*E*(E2+R*E1)/(1-R^2))
730 Q1=(2*E4-EO-E9)/(EO-E9)
740 C1=(ATN(Q1))/2
750 T1=C1/1.745329E-02
760 IF T1>45 THEN 770 ELSE 790
770 D1=T1-90
780 GOTO 890
790 IF T1<-45 THEN 800 ELSE 820
800 D1=T1+90
810 GOTO 890
820 D1=T1
830 IF A=0 GOTO 890
840 REM ESTIMATE OF STRESS TENSOR WITH AXIAL STRAIN READINGS
850 Z=(1-2*R)*(1+R)
860 S2=(.001*E/Z)*(E2+R*(E1-E2+A))
870 S1=S2+(.001*E/(1+R))*(E1-E2)
880 A1=S2-(.001*E/(1+R))*(E2-A)
890 IF EO>E9 THEN 900 ELSE 920
900 LPRINT"AXIAL   AND    MAJOR AND MINOR STRESSES(MPA),ANGLE OF MAJOR STRESS"
910 GOTO 930
920 LPRINT"AXIAL   AND    MAJOR AND MINOR STRESSES(MPA),ANGLE OF MINOR STRESS"
930 LPRINT A1, S1, S2, D1
940 GOTO 400
950 END
```

```
ELASTIC MODULUS(GPA), POISSON'S RATIO, BOREHOLE DIA.(MM)
 69              .25             76
CALIBRATION FACTORS KO,K4 AND K9 IN MM/HZ
 .0.04           .00038          .00042
DATE, BOREHOLE MICRO-STRAINS AT 0, 45, AND 90 DEGREES
 881121          310.5263        80              49.73685
AXIAL    AND    MAJOR AND MINOR MICRO-STRAINS
 100             344.5377        15.72546
AXIAL    AND    MAJOR AND MINOR STRESSES(MPA),ANGLE OF MAJOR STRESS
 18.22326        31.72175        13.57131        -18.76053
```

NOTE: A copy of the above program is available on disk from:

Mining Research Laboratories
CANMET
555 Booth Street
Ottawa, Ontario, K1A 0G1
Canada

Please quote report number.

```
100 REM PROGRAM HV-MRL/CANMET-HERGET NOV. 1989
110 REM PROGRAM CALCULATES STRESS CHANGES IN MPA FOR CHANGES IN FREQUENCY
120 REM (HERTZ) RECORDED BY CANMET STRAIN MONITORS IN BOREHOLES.
130 REM COMPRESSIVE STRESSES ARE POSITIVE AND REDUCTION IN LENGTH
140 REM PRODUCES POSITIVE STRAINS.
150 REM INPUT IS: 270 E=ELASTIC MODULUS(GPA),280 R=POISSON'S RATIO, 290 B1=
160 REM BOREHOLE DIAMETER(MM), 310 K0=CALIBRATION FACTOR(MM/HZ) FOR
170 REM FREQUENCY READING(HZ) IN H0(=HORIZONTAL) DIRECTION, K9=CALIBRATION
180 REM FACTOR FOR H9(=VERTICAL) DIRECTION. 400 DATA 881121(DATE OF
190 REM MEASUREMENT,N),59(H0=HORIZONTAL READING),9(H9=VERTICAL READING),
200 REM 100(A=STRAIN READING FOR DIRECTION PARALLEL TO BOREHOLE FROM
210 REM EXTENSOMETER,ETC.. IF READING FOR "A" IS NOT AVAILABLE, INPUT "0"
220 REM AND S1 AND S2 ARE SECONDARY PRINCIPAL STRESSES CORRESPONDING TO
230 REM STRAINS E1 AND E2. IF READINGS FOR "A" ARE AVAILABLE, THE PROGRAM
240 REM ASSUMES THAT THE BOREHOLE DIRECTION IS A PRINCIPAL STRESS DIRECTION
250 REM AND CALCULATES THREE PRINCIPAL STRESSES.
260 REM THE ANGLE FOR THE MAJOR OR MINOR STRESS PERPENDICULAR TO THE
270 REM BOREHOLE AXIS IS GIVEN IN DEGREES ANTICLOCKWISE (+) FROM HORIZONTAL
280 REM RIGHT WITH AN OBSERVER LOOKING INTO THE DRILLHOLE.
290 E=69
300 R=.25
310 B1=76
320 K0=.0004
330 K9=.00042
340 LPRINT"ELASTIC MODULUS(GPA), POISSON'S RATIO, BOREHOLE DIA.(MM)"
350 LPRINT E,R,B1
360 LPRINT"CALIBRATION FACTORS K0 AND K9 IN MM/HZ"
370 LPRINT K0,K9
380 READ N,H0,H9,A
390 DATA 881121,59,9,100
600 E0=1000000!*H0*K0/B1
610 E9=1000000!*H9*K9/B1
620 LPRINT"DATE, BOREHOLE MICRO-STRAINS AT 0 AND 90 DEGREES"
630 LPRINT N, E0, E9
640 IF E0>E9 THEN 650 ELSE 680
650 E1=E0
660 E2=E9
670 GOTO 700
680 E1=E9
690 E2=E0
700 LPRINT"AXIAL   AND    MAJOR AND MINOR MICRO-STRAINS"
710 LPRINT A, E1, E2
720 S1=(.001*E*(E1+R*E2)/(1-R^2))
730 S2=(.001*E*(E2+R*E1)/(1-R^2))
740 IF A=0 GOTO 800
750 REM ESTIMATE OF STRESS TENSOR WITH AXIAL STRAIN READINGS
760 Z=(1-2*R)*(1+R)
770 S2=(.001*E/Z)*(E2+R*(E1-E2+A))
780 S1=S2+(.001*E/(1+R))*(E1-E2)
790 A1=S2-(.001*E/(1+R))*(E2-A)
800 IF E0>E9 THEN 810 ELSE 830
810 LPRINT"AXIAL   AND    MAJOR AND MINOR STRESSES(MPA),ANGLE OF MAJOR STRESS"
820 GOTO 840
830 LPRINT"AXIAL   AND    MAJOR AND MINOR STRESSES(MPA),ANGLE OF MINOR STRESS"
840 LPRINT A1, S1, S2,"HORIZONTAL"
850 GOTO 380
860 END
```

```
ELASTIC MODULUS(GPA), POISSON'S RATIO, BOREHOLE DIA.(MM)
 69              .25             76
CALIBRATION FACTORS KO AND K9 IN MM/HZ
 .0004           .00042
DATE, BOREHOLE MICRO-STRAINS AT 0 AND 90 DEGREES
 881121          310.5263        49.73685
AXIAL    AND    MAJOR AND MINOR MICRO-STRAINS
 100             310.5263        49.73685
AXIAL    AND    MAJOR AND MINOR STRESSES(MPA),ANGLE OF MAJOR STRESS
 18.22326        29.84432        15. 4874      HORIZONTAL
```

NOTE: A copy of the above program is available on disk from:

Mining Research Laboratories
CANMET
555 Booth Street
Ottawa, Ontario, K1A 0G1
Canada

Please quote report number.